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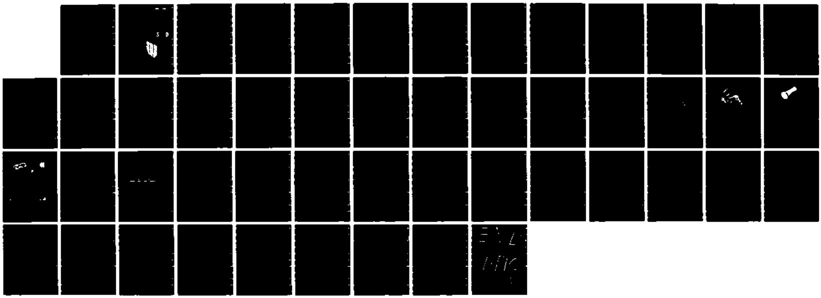

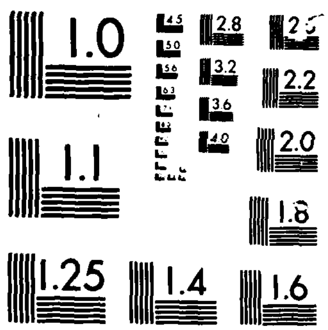

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US Army Corps of Engineers
Construction Engineering Research Laboratory

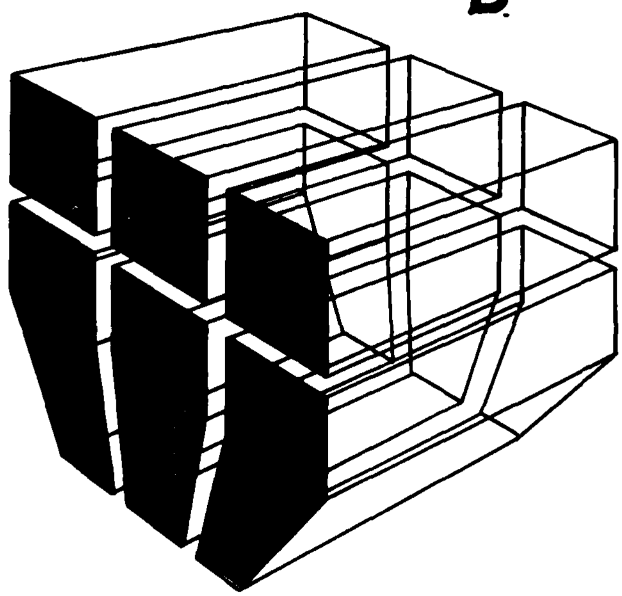
USA-CERL

TECHNICAL REPORT N-86/05
March 1986
Closed-Loop Water Conservation/Supply Augmentation Techniques

AD-A167 556

Preventing Water Loss in Water Distribution Systems: Money-Saving Leak Detection Programs

by
Stephen W. Maloney
Richard J. Scholze
John T. Bandy



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A procedure is described for making a water loss survey part of an installations' regular maintenance program. The survey would consist of three levels: (1) "housekeeping," in which facility and residential fixtures and water-using appliances are checked, (2) a water audit, which determines if losses are occurring in the distribution system and, if so, the general area of the leak, and (3) leak pinpointing by one or more of the current leak detection methods described. A procedure for estimating cost-to-benefit ratios is also given, along with a hypothetical example. The cost-effectiveness of a leak detection program depends on several factors—one of the most important of which is the water treatment/purchase cost.

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Most Army installations do not keep records of water usage for each residence and facility since military personnel pay a base rate for an unlimited supply. For this reason, it is unclear at present how much water may be wasted through loss in the distribution system (e.g., via leaks in subsurface or directly into the sanitary or stormwater sewers).

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FOREWORD

This work was performed for the Assistant Chief of Engineers, Office of the Chief of Engineers (OCE), under Project 4A162720A896, "Environmental Quality Technology"; Task Area A, "Installation Environmental Management"; Work Unit 031, "Closed-Loop Water Conservation/Supply Augmentation Techniques." The OCE Technical Monitor was R. Newsome, DAEN-ZCF-U.

The work was done by the U. S. Army Construction Engineering Research Laboratory (USA-CERL) Environmental Division (EN). Dr. R. K. Jain is Chief, EN.

COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

FIGURES

FIGURES (Cont'd)

PREVENTING WATER LOSS IN WATER DISTRIBUTION SYSTEMS: MONEY-SAVING LEAK DETECTION PROGRAMS

1 INTRODUCTION

Background

Water historically has been a low-value commodity except in arid regions. However, as the world population becomes increasingly urbanized and industrialized, even humid areas have had water shortages due to the high concentration of people and the adverse effects of industrial and domestic pollution discharges on existing water supplies. As a result, potable water supplies have become more valuable, mandating actions to prevent water loss through waste and leakage.

U. S. Army installations are unique in that although they distribute water much like a municipality, military personnel do not pay for their water by the gallon; they pay a fixed amount for an unrestricted supply. Therefore, the monetary incentive to conserve water is missing, as are many other built-in control mechanisms such as water meters to monitor usage. This situation makes it difficult to obtain a clear picture of how much water is being consumed, wasted, and lost in transit. In fact, the first organized effort at evaluating overall water usage on military bases has been recent.[1]

Water loss in distribution systems is a common problem, but is difficult and often uneconomical to detect and correct. Since most system components are located below-grade, visual inspection is not useful unless a major breakage occurs and sends water to the surface.

Leak detection services are available from the Facilities Engineering Support Agency (FESA) of the U. S. Army Corps of Engineers (USACE). However, FESA's services usually are employed to locate problem-causing leaks, such as those producing an emergency situation. To minimize expenses due to water leakage, Army installations need methods for detecting leaks early, before a major breakage occurs. Methods that could potentially meet this need have been developed and should be assessed for effectiveness and economy. When incorporated as part of a regular operation and maintenance (O&M) procedures, early leak detection techniques potentially could save money, help prevent losses of potable water, and help prevent major breakages.

Objectives

The objectives of this study were to (1) identify techniques and establish a methodology for detecting leaks in water distribution systems at Army installations that have limited records of individual water use and (2) perform an economic analysis of any cost savings and benefits that could be derived from early leak detection programs.

[1] J. T. Bandy and R. J. Scholze, *Distribution of Water Use at Representative Fixed Army Installations*, Technical Report N-157/ADA133232 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], August 1983).

Approach

The literature and field were surveyed to learn which methods represent the state of the art in early water leak detection. The techniques identified were divided into three levels, from simple, inexpensive tasks to complex, more costly analyses: (1) "general housekeeping," (2) methods for showing the existence of excessive water loss, and (3) methods for pinpointing leaks, as follows:

1. A series of housekeeping leak checks for surveying interior water fixtures was developed.

2. Guidelines for surveying water loss at sections of the water distribution system were established, with the required equipment and minimum training for operating personnel described.

3. The more sophisticated methods for detecting leaks in the distribution system were described and analyzed for applicability at Army installations.

Finally, costs and benefits of an early leak detection program were estimated.

Mode of Technology Transfer

Information in this report may impact Technical Manuals (TM) 5-813-1, *Water Supply: General Considerations*, and 5-660, *Maintenance and Operation of Water Supply Treatment and Distribution Systems*. An Engineer Technical Letter containing this information will be published.

2 WATER LOSS IN DISTRIBUTION SYSTEMS

"Water loss" in this report is considered that physically lost from the distribution system. For a municipal or private water supply, lost water also could include categories such as public use, e.g., unmetered water fountains, public buildings, fire-fighting demands (through unmetered fire hydrants), and unauthorized water connections. These categories have one common trait--they lose water revenue for the utility because they represent unmetered usage. Water physically escaping from the system represents not only lost revenue, but also a lost resource in a real as well as economic sense.

Leak Occurrence

Water loss from distribution systems has been characterized as occurring through leaks and breaks.[2] Leaks result from loose joints or service connections; breaks occur when a water main fractures. In this respect, inadequate joint sealing is separate from structural failure. The main reasons for structural failure are excessive load, low temperatures, and corrosion.

Water mains usually are designed to withstand all anticipated loads. Thus, structural failure can occur when the load conditions change or when a system is designed inadequately. Load conditions can change due to corrosion of the exterior pipe wall or erosion of the bedding support. Cast iron water mains can corrode in a way that depletes the ferric content, leaving behind weaker graphitic material. The degree of corrosion depends on the soil type and other environmental conditions. Bedding support erosion can occur when a small leak slowly washes away surrounding fill until a cavity is formed around the pipe. The original force/stress relationships then become invalid and pipes can fail. Thus, the forces producing structural failure do not necessarily act independently of each other.

Excessive internal loads result in hoop stress failure; excessive external loads can lead to ring failure, crushing, or complete beam failure. Beam failure usually produces a circumferential break, whereas crushing failure results in longitudinal cracks. Continuous changes in force can cause fatigue failure at joints, which results in leakage rather than complete breakage.

Temperature affects mains in two ways: (1) increased tensile stress from contraction and expansion due to temperature fluctuations, and (2) increased external forces from soil moisture expansion during frost penetration. Water mains are designed with flexible bell-spigot joints to avoid problems with contraction, but other structures may restrict movement, leading to excessive stress. Mains also are designed to withstand frost penetration, but surface erosion or unusual weather conditions can expose them to stress levels higher than anticipated.

Temperature can also be the "straw that breaks the camel's back." That is, mains already weakened by corrosion and/or subjected to excessive loads may break during very

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[2] D. K. O'Day, "Organizing and Analyzing Leak and Break Data for Making Main Replacement Decisions," *Journal of the American Water Works Association (JAWWA)*, Vol 74, No. 11 (November 1982).

cold weather. For example, more than half of all main breaks in the northern United States occur during November through February.[3]

Amount of Water Loss

Estimating the amount of water leaking from a distribution system is complicated and is further confounded by the absence of reliable records (from meters) for water consumption. In theory, a mass balance can be computed by summing total water usage from individual customers' meters and subtracting this total from the total water pumped into the system. However, meters often are inaccurate or absent on Army installations. Common practice for municipal authorities has been to not meter public buildings because water charges for these buildings would represent an unnecessary internal billing. This same philosophy has been generally applied at Army installations (i.e., all buildings are considered public); thus, simple mass balances usually are not possible to compute.

Without water meters, a general indication of excessive water use or loss can be determined by comparing day and night water usage rates. Fluctuations in domestic water usage have been well documented in controlled studies.[4] Data from a 90°F day indicate that water use can vary from less than 100 gal/day per dwelling unit during the early morning (0200-0500 hr) to greater than 1400 gal/day per dwelling unit in the evening (1700-2100 hr). Water demands arising from leaks would not fluctuate in the same way, in that they depend primarily on system pressure--a condition determined mainly by elevated storage. Elevated storage is depleted during periods of high usage so that overall system pressure (and water lost through leaks) decreases. The tanks are refilled during low usage times. Thus, maximum water losses occur when the elevated tanks are nearly full--typically in the early morning. This tends to increase the ratio between night and day use. Therefore, even though meter records are not available, the severity of water loss can be estimated.

The ratio of early morning to evening usage also can be used to locate leakage areas by partially valving off sections of the distribution system and determining the ratio for each section. The distribution system is subdivided into sections fed by only one or a few mains and the flow in those few mains is then determined. This method leads to a point of diminishing returns because determining the flow in a main requires insertion of a flowmeter, and the number of flowmeters increases dramatically as the size of the subsections decreases.

In addition to using day/night use ratios, the size of the water loss problem on Army installations can be appreciated from the viewpoint of total water main length, as recorded by FESA for components under Army responsibility. The 167 installations reporting have a total water main length equal to approximately 9400 mi. The length ranges from over 2 million linear feet at Fort Bragg to as low as 75 linear feet. Table 1 summarizes these data showing Army installations in decreasing order by reported size of distribution system.

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[3] W. H. Smith, "Frost Loadings on Underground Pipe," *JAWWA*, Vol 68, No. 12 (December 1976).

[4] J. W. Clark, W. Viessman, Jr., and M. J. Hammer, *Water Supply and Pollution Control* (Intext Educational Publishers, 1971).

Water for which the particular use is unaccounted has been estimated at four fixed Army installations.[5] The estimates were developed metering the water lines at a small sample of buildings. Values determined at these buildings were then used to extrapolate usage for the entire installation. Water loss is a subset of "unaccounted-for water," but a high value for unaccountable usage usually indicates substantial water loss is occurring. The amount of unaccounted-for water ranged from 9 to 36 percent on the four installations--Forts Bliss (9 percent), Carson (9 percent), Bragg (36 percent), and Lewis (26 percent).

The water industry has developed several methods to detect leaks in water distribution systems. Most involve detection of sounds associated with leaks; others use tracer gases. There are at least three levels of sophistication in sound detection, ranging from mechanical geophones to sound amplifiers to electronic analysis of amplified sounds. As the level of sophistication increases, so does the cost. Tracer gas methods are the most expensive, sometimes requiring dewatering of a water main and expensive, complex instrumentation for gas detection.

Leak Detection/Mitigation Program

Army installations could establish a program for early leak detection using the three levels of methods described in Chapter 1. In following such a program, the installation would first conduct a "housekeeping" leakage survey to minimize water loss in the most controllable environment--water fixtures with easy access. Second, a water loss survey would be conducted to determine the extent of any problem(s) found. Third, in sections of the installation that have excessive water loss, a pinpointing survey would be conducted to locate leaks. The pinpointing survey would use methods with increasing levels of sophistication until the water loss, as determined by a continuing level 2 survey, reaches an acceptable level. This level will be determined based on local cost and availability of water and on the cost of required repairs.

[5]J. T. Bandy and R. J. Scholze.

Table 1
Summary of Pipe Length on Army Installations

Location	Length	Percent	Cumulative Percent
Fort Bragg	2,102,630	4.26	4.26
Fort Hood	1,754,641	3.55	7.81
Fort Bliss	1,475,958	2.99	10.80
Hawthorne Army Ammunition Plant	1,368,612	2.77	13.57
Fort Huachuca	1,303,530	2.64	16.21
Fort Shafter	1,272,572	2.58	18.78
Fort Lewis	1,265,083	2.56	21.34
Fort Riley	1,254,672	2.54	23.88
Fort Knox	1,170,909	2.37	26.25
Fort Ord	1,120,687	2.27	28.52
Sunflower Army Ammunition Plant	1,042,915	2.11	30.63
Fort Campbell	1,009,187	2.04	32.68
Fort Wainwright	999,613	2.02	34.70
Fort Benning	904,245	1.83	36.53
Aberdeen Proving Ground	892,524	1.81	38.34
Fort Sam Houston	874,217	1.77	40.11
Tooele Army Depot	860,518	1.74	41.85
Redstone Arsenal	845,823	1.71	43.56
Fort Leonard Wood	823,163	1.67	45.23
Radford Army Ammunition Plant	814,919	1.65	46.88
White Sands Missile Range	791,116	1.60	48.48
Fort Sill	771,531	1.56	50.04
Fort George G. Meade	748,286	1.51	51.55
Fort Belvoir	735,630	1.49	53.04
Fort Jackson	695,978	1.41	54.45
Fort Devens	663,193	1.34	55.80
Badger Army Ammunition Plant	630,612	1.28	57.07
McAlester Army Ammunition Plant	621,931	1.26	58.33
Fort Stewart	614,796	1.24	59.58
Fort Carson	596,430	1.21	60.78
Fort Dix	579,755	1.17	61.96
Fort Lee	572,545	1.16	63.12
Fort Gordon	550,882	1.12	64.23
Red River Army Depot	512,626	1.04	65.27
Fort Eustis	512,406	1.04	66.31
Indiana Army Ammunition Plant	500,175	1.01	67.32
Fort McClellan	496,105	1.00	68.32
Fort Richardson	470,432	0.95	69.27
Joliet AAP Kankakee	444,645	0.90	70.17
Fort Pickett	437,127	0.88	71.06
Fort McCoy	432,829	0.88	71.94
Lone Star Army Ammunition Plant	417,793	0.85	72.78
Letterkenny Army Depot	403,946	0.82	73.60
California Other	386,187	0.78	74.38
Fort Rucker	382,399	0.77	75.16
Fort Drum	368,943	0.75	75.90

Table 1 (Cont'd)

Location	Length	Percent	Cumulative Percent
California National Guard	365,985	0.74	76.64
North Dakota Other	343,361	0.70	77.34
Fort Gillem	336,712	0.68	78.02
Iowa Army Ammunition Plant	333,662	0.68	78.70
Fort Polk	332,960	0.67	79.37
Fort Indiantown Gap	332,084	0.67	80.04
Fort Leavenworth	331,154	0.67	80.71
Presidio of San Francisco	327,576	0.66	81.38
Louisiana Army Ammunition Plant	308,508	0.62	82.00
Anniston Army Depot	286,926	0.58	82.58
Milan Army Ammunition Plant	284,480	0.58	83.16
Kansas Army Ammunition Plant	273,618	0.55	83.71
Ravenna Army Ammunition Plant	266,138	0.54	84.25
Fort Monmouth	265,358	0.54	84.79
Yuma Proving Ground	260,546	0.53	85.31
Pine Bluff Arsenal	258,944	0.52	85.84
Hunter Army Airfield	251,713	0.51	86.35
West Point Military Residences	244,773	0.50	86.84
Sierra Army Depot	238,313	0.48	87.33
Dugway Proving Ground	230,821	0.47	87.79
Fort Sheridan	221,075	0.45	88.24
Fort Monroe	220,205	0.45	88.69
Fort Benjamin Harrison	211,795	0.43	89.11
Volunteer Army Ammunition Plant	209,334	0.42	89.54
Fitzsimmons AMC	206,854	0.42	89.96
Seneca Army Depot	192,290	0.39	90.35
Defense Depot Ogden	180,333	0.37	90.71
Fort Detrick	168,469	0.34	91.05
Picatinny Arsenal	160,020	0.32	91.38
Cornhusker Army Ammunition Plant	149,683	0.30	91.68
Fort Lesley J. McNair	147,285	0.30	91.98
Longhorn Army Ammunition Plant	137,754	0.28	92.26
Fort Ritchie	136,129	0.28	92.53
Fort Hamilton	134,556	0.27	92.80
Rocky Mountain Arsenal	121,798	0.25	93.05
Twin Cities Army Ammunition Plant	121,577	0.25	93.30
Defense General Supply Center	120,017	0.24	93.54
Defense Depot Memphis	114,383	0.23	93.77
St. Louis Area Support Center	113,986	0.23	94.00
Sharpe Army Depot	113,136	0.23	94.23
Jefferson Proving Ground	109,697	0.22	94.45
Lake City Army Ammunition Plant	104,891	0.21	94.67
New Cumberland Army Depot	101,926	0.21	94.87
Fort Hunter Ligget	100,217	0.20	95.07
Tracy Defense Depot	96,521	0.20	95.27
Defense Construction Supply Center	95,601	0.19	95.46

Table 1 (Cont'd)

Location	Length	Percent	Cumulative Percent
N/A*	95,279	0.19	95.66
Arlington National Cemetery	94,732	0.19	95.85
Rock Island Arsenal	93,790	0.19	96.04
Bayonne MOT	91,860	0.19	96.22
Oakland Army Base	89,227	0.18	96.40
Newport Army Ammunition Plant	87,850	0.18	96.58
Tobyhanna Army Depot	85,301	0.17	96.76
Presidio of Monterey	84,608	0.17	96.93
Nevada Other	80,034	0.16	97.09
Fort McPherson	79,625	0.16	97.25
Oakdale Support Facility	75,927	0.15	97.40
Carlisle Barracks	70,916	0.14	97.55
Walter Reed AMC	69,947	0.14	97.69
Cameron Station	68,170	0.14	97.83
Alabama Army Ammunition Plant	67,368	0.14	97.96
Vint Hill Farms Station	62,268	0.13	98.09
Sacramento Army Depot	61,934	0.13	98.21
Fort A. P. Hill	61,188	0.12	98.34
Oklahoma National Guard	55,416	0.11	98.45
Fort Myer	51,415	0.10	98.55
Fort Greely	46,680	0.09	98.65
Lima Army Tank Center	42,442	0.09	98.74
Mississippi Army Ammunition Plant	41,406	0.08	98.82
Fort Douglas	39,218	0.08	98.90
Brooklyn MOT	39,061	0.08	98.98
Holston Army Ammunition Plant	35,061	0.07	99.05
Watervliet Arsenal	32,875	0.07	99.11
Pennsylvania National Guard	30,870	0.06	99.18
Riverbank Army Ammunition Plant	28,688	0.06	99.24
Pennsylvania Other	24,493	0.05	99.29
Utah National Guard	18,480	0.04	99.32
Arlington Hall Station	18,267	0.04	99.36
Maryland National Guard	17,889	0.04	99.40
Detroit Arsenal	16,948	0.03	99.43
Montana National Guard	16,925	0.03	99.46
Missouri National Guard	16,027	0.03	99.50
Georgia National Guard	15,643	0.03	99.53
Defense Personnel Support Center	14,925	0.03	99.56
Texas National Guard	14,481	0.03	99.59
Natick Developmental Center	13,455	0.03	99.62
Florida National Guard	13,162	0.03	99.64
Stratford Army Eng Plant	12,315	0.02	99.67
Whittier Anchorage Pipeline	12,199	0.02	99.69
Maryland Other	11,038	0.02	99.71

*Installation name was not available on the FESA Database.

Table 1 (Cont'd)

Location	Length	Percent	Cumulative Percent
U.S. Army Mat & Mech Research Center	9,425	0.02	99.80
New Mexico National Guard	7,749	0.02	99.81
Harry Diamond Labs	6,924	0.01	99.82
Fort McPherson Recreational Area	6,725	0.01	99.84
Gateway Army Ammunition Plant	6,651	0.01	99.85
Detroit Arsenal Tank Plant	6,220	0.01	99.86
Yakima Research Station	6,098	0.01	99.88
Virginia National Guard	5,886	0.01	99.89
St. Louis Army Ammunition Plant	5,002	0.01	99.90
Alaska National Guard	4,771	0.01	99.91
New Jersey National Guard	4,755	0.01	99.92
Nebraska National Guard	4,462	0.01	99.93
Massachusetts Other	4,448	0.01	99.94
Cold Regions Research Laboratory	4,152	0.01	99.94
Hays Army Ammunition Plant	4,073	0.01	99.95
Ethan Allen Fire Range Underhill	3,965	0.01	99.96
Rhode Island Other	3,406	0.01	99.97
Rhode Island National Guard	3,313	0.01	99.97
Illinois National Guard	3,232	0.01	99.98
Washington National Guard	3,188	0.01	99.99
Ohio National Guard	2,455	0.00	99.99
Columbus Support Facility	1,102	0.00	99.99
Utah Other	890	0.00	100.00
Louisiana Other	736	0.00	100.00
U. S. Army Fuels & Lub. Research Lab	700	0.00	100.00
Kentucky Other	137	0.00	100.00
New York National Guard	110	0.00	100.00
National Security Agency	75	0.00	100.00
Missouri Other	0	0.00	100.00
Fort Chaffee	0	0.00	100.00
North Carolina National Guard	0	0.00	100.00
Michigan National Guard	10,906	0.02	99.74
Saginaw Army Aircraft Plant	10,382	0.02	99.76
Scranton Army Ammunition Plant	9,450	0.02	99.78

3 LEVEL 1—HOUSEKEEPING LEAKAGE SURVEY

Leaks at water fixtures and water-using appliances are generally outside the domain of public water utility concern with respect to detection because the leaks are on the private owners' side of the water meter. If the meter is functioning properly, the customer is responsible for the cost of water lost to leakage; thus, there is no direct monetary gain for the water utility if the leak is repaired. Since the customer would benefit from the repair, it is assumed that person would correct any leaks causing substantial water loss--otherwise the water bill may increase. For example, a slow leak in a water closet produces no inconvenience due to water spillage (because the water goes directly into the sewage collection system), but the water bill can increase 50 to 100 percent; a water bill of $90 (quarterly) that increases to as much as $180 is enough impetus to the customer to correct the problem.

The billing incentive does not exist on Army installations, with the effect that serious leaks may not be repaired. In the data taken recently at Army bases, one extreme case was observed in which the usage for a household was measured at 11,000 gal/day.[6] (A normal household of four persons should have a usage of 400 to 1000 gal/day.) In private residences, this rate could translate into a quarterly bill of $1000. The 11,000-gal/day rate probably is due to leakage in the lateral going to the house or directly into a drain. Identifying and correcting problems like this can save thousands of dollars.

The lack of meters at Army installations means dramatic changes in water use at an individual building can go unnoticed. The cumulative effects of leaks in many buildings also can be undetected if they occur gradually over time. Detecting water leaks on the user's side of the meter is a simple task that could be done by the installation Directorate of Engineering and Housing (DEH) office. Certain areas should be checked before a water audit is performed so that excessive use can be attributed to leaks in the distribution system, rather than to a mixture of interior plumbing and pipeline losses.

All exposed fixtures should be visually inspected. The inspection should include all joints and connections such as water faucets, water heaters, shutoff valves, and exposed plumbing. Water closets can be checked for leaks by placing a few drops of a dye (e.g., food coloring) into the toilet tank, and observing the tank 15 minutes later. If the dye appears in the bowl, it indicates that water is leaking through the toilet tank plunger seal.

All water-using appliances (e.g., air-conditioners) should be checked for proper connections and water flow within design ranges. For any appliances for which proper water demand is unknown or not reported in instruction manuals, check with the manufacturer for specifications.

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[6] J. T. Bandy and R. J. Scholze.

4 LEVEL 2—WATER AUDIT

The term "water audit" can be used to include meter testing, leak detection and quantification, distribution system inventory, and a review of recordkeeping and water-accounting procedures. For this report, "water audit" means quantification of water uses by water distribution system district or subdistrict. To illustrate the procedure, a hypothetical water distribution system is discussed as shown in Figure 1.

For the model installation, all water is purchased from a private water utility through three master meters located on that utility's transmission main. All installation facilities are located southeast of the transmission main. Most distribution mains are part of a "loop" rather than a "tree," so that water can flow to one location from more than one direction. This setup greatly improves a system's efficiency and is common in well designed water distribution systems; however, it complicates the water audit procedure.

A water audit is conducted by segmenting the distribution system into districts and then measuring the total flow into these districts over a 24-hr period. Again, the looped systems, while advantageous for providing water service, make this segmenting difficult. One of two procedures is chosen to segment the district: (1) close the valves in pipes connecting two adjacent districts or (2) place a flowmeter in a pipe connecting two districts. At least one flowmeter is required; more may be required for larger districts for which the demand may exceed the capacity of the single distribution main when all other connections are valved off.

Using the hypothetical system, Figure 2 shows a method to divide the entire system into two large districts. Depending on the demand in each district and the sensitivity of the master meters, it may be possible in this example to conduct a preliminary water audit on two districts using only the master meters. More likely, however, is that several districts will be needed as shown in Figure 3.

The choice of districts must consider:

1. Availability of working valves that could isolate a certain district.

2. Feasibility of locating a flowmeter, which requires excavating and exposing a pipe segment and inserting a pitot tube.

3. Capacity of the pipe section (in which flow is being measured) to meet the normal demands for water. Note that pipe sizes usually are dictated by fire flow demands, which are much greater than normal demands. Thus, closing a valve does not necessarily mean water service will decrease greatly. The closing of valves must be coordinated closely with the fire marshal, and care must be taken to use valves that have been exercised and are known to be in working order. Caution is always needed because old valves may stick or remain closed after the test.

Once the districts are chosen, a pitot tube is placed into the distribution system. This task requires exposing part of a main and tapping a corporation connection into it. The pitot tube is inserted into the main through the connection, and water flow is determined based on differences in static and dynamic pressure. The pitot tube is then removed and the valve on the connection is closed. Figure 4 shows a pitot tube inserted into a water main. The difference in pressure is shown as "D" on the figure.

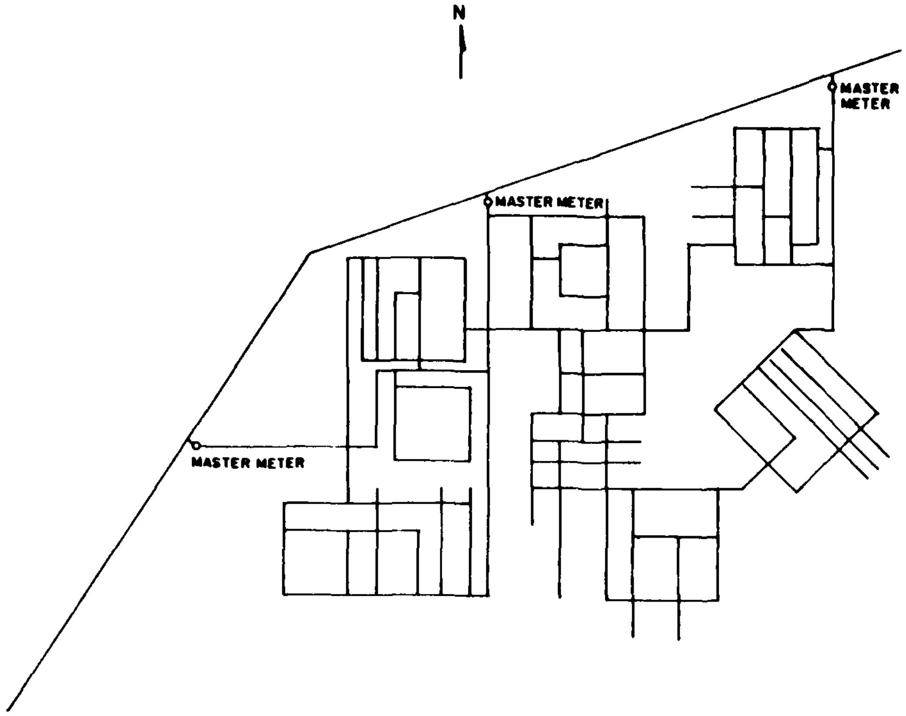

Figure 1. Hypothetical water distribution system.

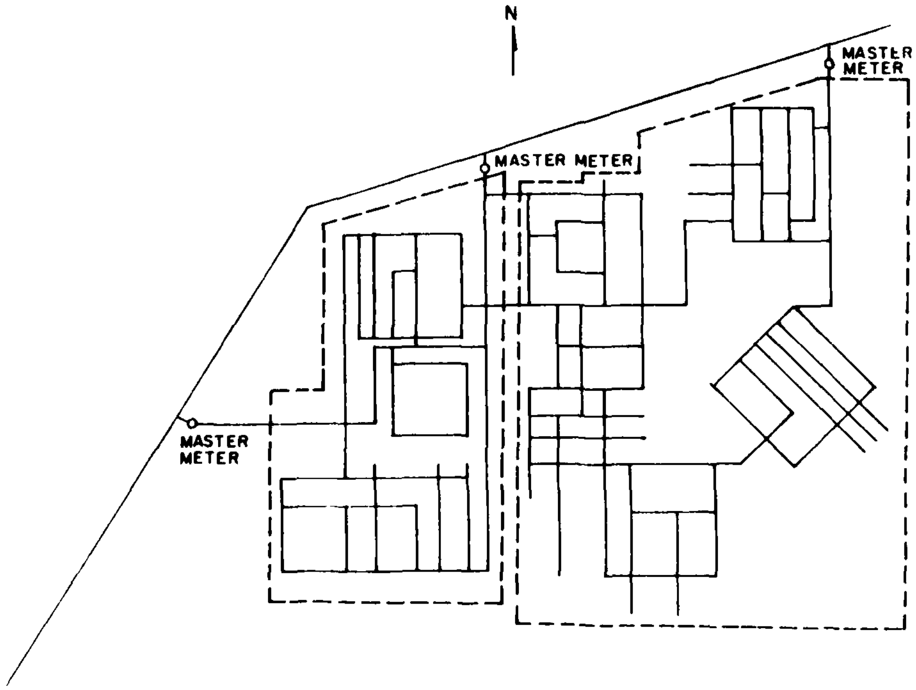

Figure 2. Water distribution system divided into two subdistricts.

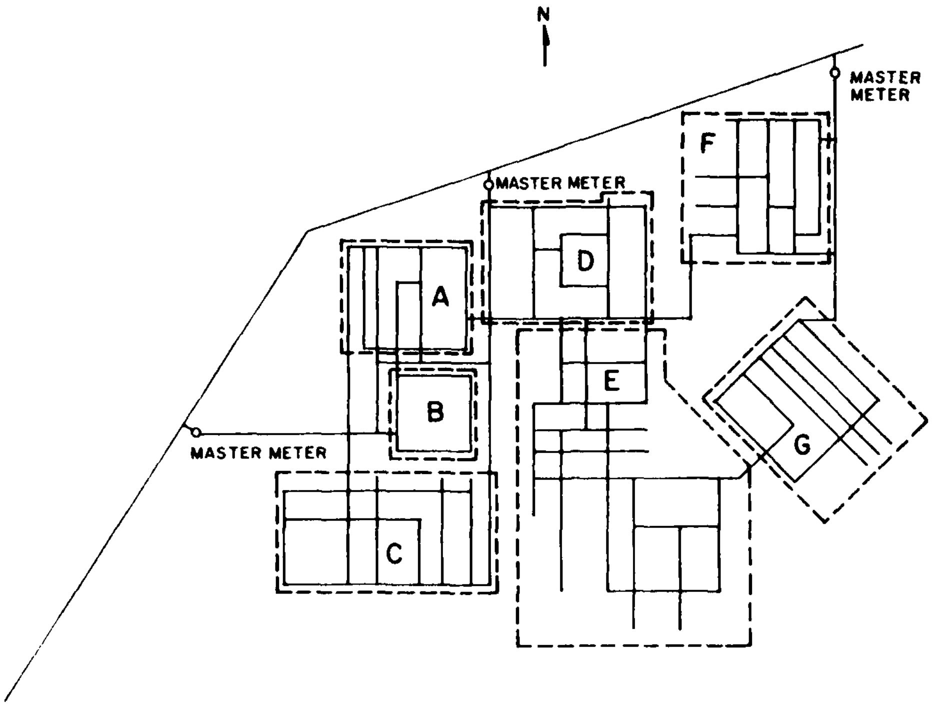

Figure 3. Water distribution system divided into seven subdistricts.

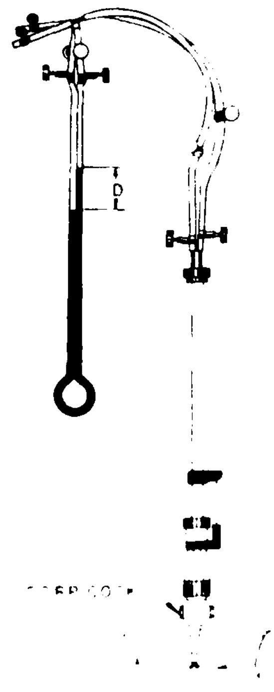

Figure 4. Pitot tube inserted into water main.

The results of the flow tests show the amount of water entering a particular subdistrict. The flow can be composed of three parts: water consumption, water lost to leakage, and water transferred to storage. Thus, two additional parameters must be estimated. Facilities known to consume a large amount of water throughout the night must be subtracted from the total flow because this usage may mask water loss due to leakage in the ratio of minimum night flow to average daily flow. Similarly, any increase or decrease in elevated storage must be taken into account. Equation 1 can be used to estimate minimum night flow:

$$Q_{mnf} = Q_{in} - Q_{ind} - Q_{stor}, \qquad \text{[Eq 1]}$$

where Q_{mnf} = minimum night flow (all values gal/min); Q_{in} = net inflow into subdistrict; Q_{ind} = industrial or continuous water use; and Q_{stor} = net flow into storage (can be a negative number).

Q_{in} is determined from the pitot tubes and represents net inflow; i.e., at some locations, water will flow into a subdistrict and at other, it will flow out. The net inflow is the difference between inflow and outflow. Q_{ind} is determined by flowmeters at heavy water use locations, insertion of a pitot tube at the heavy user's intake, or estimation. Q_{stor} is determined by changes in the level of storage reservoirs. The change in level determines the quantity, which is divided by the time between readings to determine the flow rate.

The average daily flow, Q_{ave}, is determined in a similar way. The difference between the two measurements is that minimum night flow is determined between 0230 and 0430 hr, whereas average daily flow is determined over a 24-hr period as calculated in Equation 2:

$$Q_{ave} = Q_{in} - Q_{ind} - Q_{stor}, \qquad \text{[Eq 2]}$$

where Q_{ave} = average daily flow. The ratio Q_{mnf}/Q_{ave} is used to determine if water loss through leakage is a major problem in the subdistrict being analyzed. If the ratio is greater than 0.5, excessive leakage probably is a problem.[7] Subdistricts found to have excessive leakage should then be further analyzed using one or more of the techniques in Chapter 5 to pinpoint the leaks. The ratio's size indicates the severity of water loss. Districts with the largest ratios should be analyzed first to allow the greatest chance of reducing water loss substantially.

The installation DEH can perform the water audit or several contracting engineers offer such services. Some contractors prefer to go directly to level 3; however, the unique conditions on Army installations demand that a water audit always be performed, both before and after leak detection and repair, so that the benefits can be determined directly. In this way, the leak detection program's effectiveness can be measured.

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[7] Engineer Technical Letter (ETL) 1110-2-294, *Reduction in Water Loss* (U.S. Army Corps of Engineers [USACE], February 1985).

5 LEVEL 3—LEAK DETECTION SURVEY

After the water audit is completed, areas suspected of having high leakage rates should be surveyed using reliable leak detection equipment. Leak detection methods vary greatly in cost and degree of sophistication. Techniques that have been applied in public and private utilities are:

1. Visual observation
2. Sonic technology (mechanical, electronic, amplitude attenuation, and noise correlation)
3. Miniprobe sensors
4. Tracer gases
5. Infrared photography.

Visual Observation

Visual observation is the least sophisticated and least accurate method for finding leaks. Except in the case of a water main structural failure, leaks will not present visual evidence on the ground surface. However, it is common for water utilities to survey major transmission mains visually when water usage increases dramatically and suggests a main has ruptured.

Visual observation also can be helpful when construction of utilities unrelated to potable water requires excavation in the area containing water lines. In this case, if a water audit had previously suggested water loss due to leakage, the lines could be investigated directly at little additional cost. Contractors involved in the excavation should be notified early that water leakage may be a problem so they can be prepared.

Sonic Technology

In general, water leaking out of the distribution system has three characteristic sounds.[8] The first is in the 500 to 800 Hz range and originates from the leak's acting as an orifice through which the water escapes. This is the highest intensity sound generated and can travel considerable distance along the distribution network. The second type of leak sound is in the 50 to 250 Hz range and is generated by the water's impact on the surrounding soil. The third sound, also in the 50 to 250 range, resembles the sound of a fountain as the water circulates in the cavity around the leak. The latter two sounds do not travel very far in the soil and thus can be useful in pinpointing leaks.

Figure 5 illustrates the principle of sonic leak detection. Sound waves propagate from a leak in all directions. The two sounding points shown in Figure 5 are a fire hydrant and a valve box, but additional points could be used, including meters, curb stops, and air blowoffs. Furthermore, holes could be drilled along the pavement over the pipe and metallic rods inserted to contact the pipe. This procedure allows detection along long stretches of buried main for which no surface appurtenances have been installed. The sound is dampened through the pipe material and also through each connection in the system (e.g. between section of pipe, at all tees, elbows, and crosses); thus, the sound intensity at any location is an indication of nearness to the leak.

[8] P. M. Heim, "Conducting a Leak Detection Search," *JAWWA*, Vol 71, No. 2 (1979).

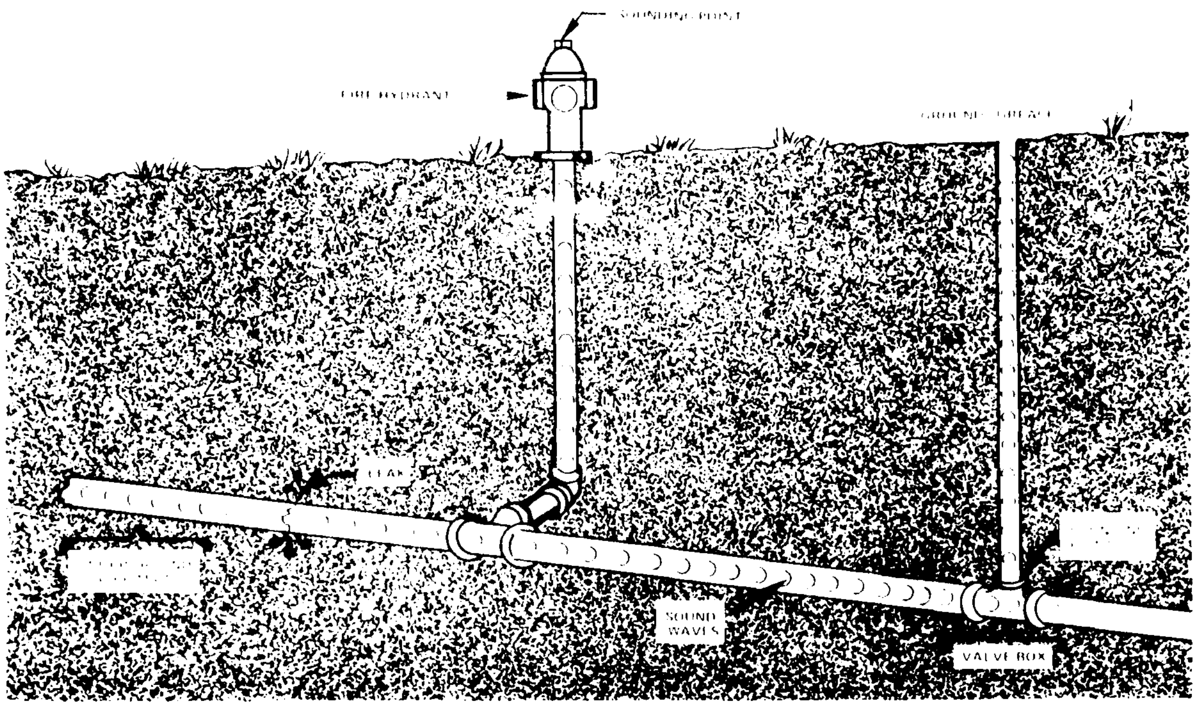

Figure 5. Principle of leak detection by sonic methods.

Mechanical Techniques

Two types of mechanical devices are in common use: the geophone and the aquaphone. In addition, metallic rods are used occasionally.

The geophone consists of two sensor disks placed on the ground and connected with the human ear via stethoscope-like earplugs and rubber tubing. These devices are not connected directly to the distribution system components and therefore pick up a great deal of extraneous noise. To use the geophone, thorough knowledge of the distribution system's layout is necessary because the survey is conducted by placing sensor disks on the ground surface over the pipes being surveyed. To minimize the effects of extraneous noise, geophones are used at night to "walk" the system. Two sensors allow the surveyor to determine the direction in which the sound increases, thus helping to pinpoint leaks. Even with night usage, however, the background noise makes operator training difficult, so that experience is the key to using this method effectively. Figure 6 shows the geophone.

Estimating the period of time required to become proficient at the use of geophones is a difficult task. Handling the apparatus can be taught in a few minutes, but the ability to distinguish between background noise and water leakage is an art that continues to develop over time. According to contacts in the water industry, a minimum of 1 week, working fulltime with an experienced surveyor, is estimated as basic training time. Also, they caution that this is a "use it or lose it" skill; thus, it should be part of one person's duties that are repeated on a regular basis.

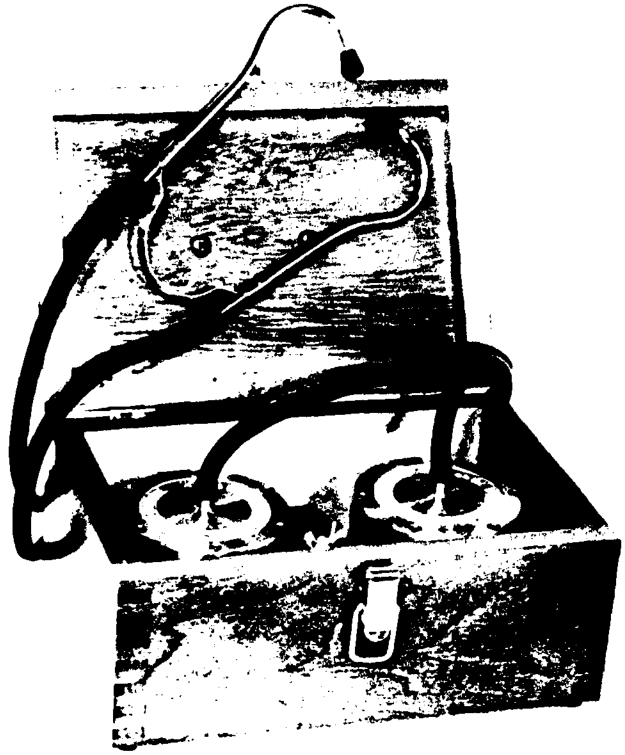

Figure 6. Geophones.

Aquaphones are hand-held devices placed in direct contact with the distribution system at fire hydrants, accessible valves, and other points. They are less sensitive than geophones and cannot be used continuously along a system--only at exposed points. They are very portable and inexpensive, and are often used to help pinpoint a leak when water is seen coming to the surface; however, they do not have the stereo effect produced by the geophones' two sensors. Figure 7 shows an aquaphone.

The training period for using an aquaphone is similar to that for a geophone. However, this instrument is less precise.

In addition to the mechanical devices described above, a metallic rod may be used as a simpler device. An operator places the rod in direct contact with the distribution system components and places the other end of the rod firmly against the front portion of the ear. This represents an older technology that requires more expertise than mechanical or electronic devices (some water treatment personnel may still use it, however).

Electronic Techniques

Electronic methods take advantage of sound amplification and noise filters and are improvements on the mechanical sonic techniques. Amplifiers and noise filters allow an operator to strengthen the signal while eliminating sounds outside the ranges characterizing a leak. The equipment consists of an acoustic pickup; electronic amplifier

Figure 7. Aquaphone.

with intensity meter; volume, frequency range, and filter controls; and headphones. Various accessories also are available to allow operators to simulate the geophone technique with a ground microphone (Figure 8) or to use extensions and/or magnets (Figure 9) to effect solid contact in a valve box (without crawling into the valve box). The tip and magnet are interchangeable and are threaded onto the probe.

The principle of sonic leak detection for electronic techniques is the same as for mechanical methods. However, some advantages are gained due to the electronic components' adaptability. For example, the acoustic pickup can be placed against a sounding point without regard to orientation because the pickup cord is flexible. Furthermore, the pickup can be lowered into valve boxes and attached to the valve by a magnet.

The signal is interpreted in the same way as for the mechanical methods except that it can be boosted by an amplifier and some of the background noise can be filtered out by selecting only the frequencies associated with leaks. Thus, general surveys could be conducted on sounds in the 500 to 800 Hz range and leaks could be pinpointed using an attachment similar to the geophone (Figure 6) while tuning in on the 50 to 250 Hz range.

Amplitude Attenuation

As sound passes through any medium, it is reduced or "attenuated" because of losses to the medium's construction material. Amplitude can be considered the strength or volume of sound, increasing closer to the sound and vice-versa. This principle is used in all sound surveys when the surveyor listens to the sound's strength and thus determines if the leak is closer or further away.

This same principle can be electronically programmed into acoustic devices and used to pinpoint leaks. Each material and type of joint has a known attenuation or sound reduction per foot. Thus, the leak locator must know the type of pipe material, number and type of joints, and where to find two sounding points on the distribution system; the internal microprocessor can then calculate the distance between the two points at which the leak is occurring.

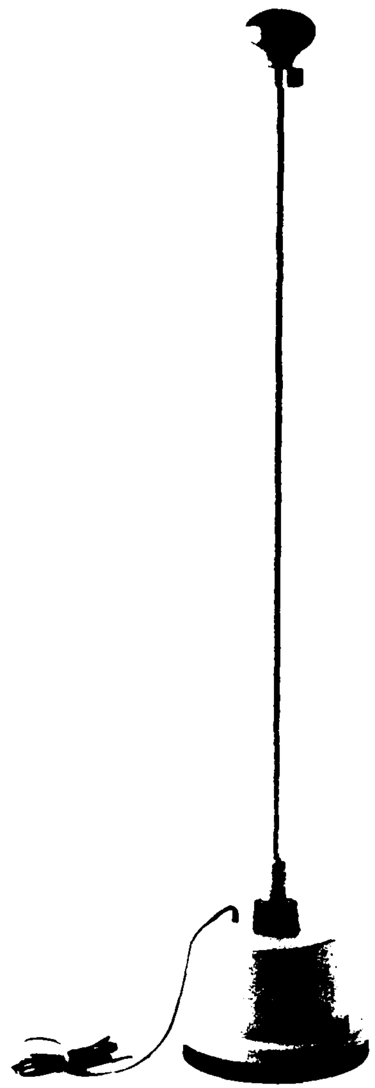

Figure 8. Ground microphone for electronic dectection of leaks.

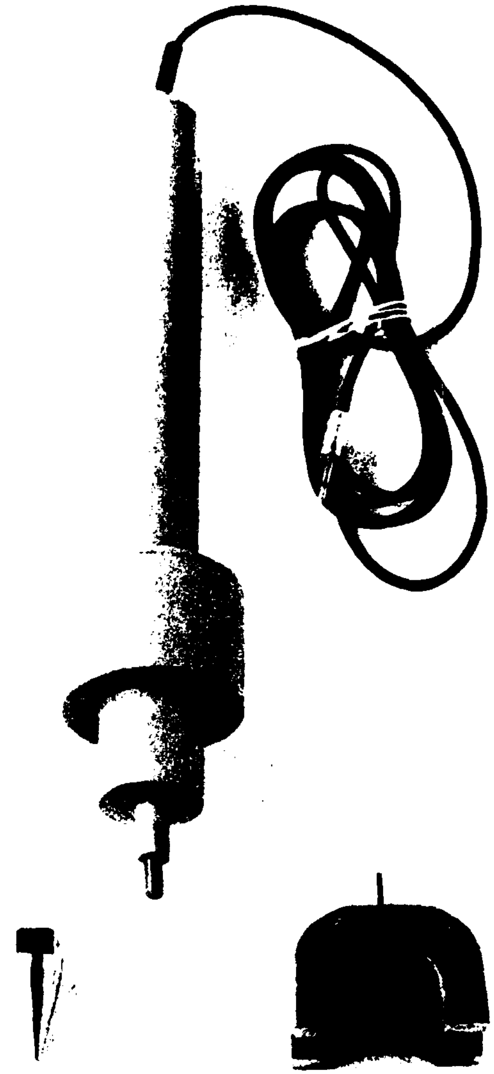

Figure 9. Probe, probe tip, and magnet for electronic detection of leaks.

This method has a second advantage in that it can detect sounds associated with leak formation. These sounds are produced as the pipe material slowly ruptures and are in the frequency range 20 to 400 kHz. This frequency is beyond the range of human hearing and even normal background noise. Therefore, it can be used without filters. In contrast, if several leaks are occurring on one pipe, the sound may be coming from several places, making leak location with this method very difficult because the amplitude does not distinguish between types of sound.

FESA uses this method for locating leaks in many types of fluid distribution systems. This type of instrument was not developed strictly for the water industry, and thus may have the broader application FESA requires. Although it has drawbacks (e.g., the interference from several leaks on the same pipe), it is far more accurate than mechanical methods that depend on the human ear and is less expensive than the correlator methods discussed in the next section.

Noise Correlation

Leaks emit noise patterns that can be analyzed and displayed on an oscilloscope. The noise patterns travel at a speed determined by the material through which they are traveling. Thus, a leak can be pinpointed in a pipe by using two electronic leak detectors and a microprocessor to analyze the noise waves. The major difference between this method and amplitude attenuation is that it pinpoints based on the wave pattern (quality) of sound rather than the amplitude (quantity).

Each electronic unit detects the noise pattern and transmits it to a central unit (correlator). The wave patterns should be nearly identical but should arrive at the correlator at different times (unless the leak is *exactly* halfway between the sounding points). The resulting waves are thus "out of phase" with each other. The correlators' electronic components automatically determine to what degree the waves are out of phase and from this, the location between the two sounding points can be determined. The most modern correlators will calculate the location between the two points automatically once the pipe size and material have been entered into the microprocessor.

Figure 10 shows an application of the noise correlator. The two acoustic pickups can be connected directly to the correlator or can use radio telemetry to transmit the signal (Figure 10). All pipe lengths must be known in detail, including the distance between the sounding point (e.g., a fire hydrant) and the buried transmission main.

This method is not necessarily foolproof in that it depends heavily on the accuracy of distribution system maps. Also, since the wave front velocity will change as the wave passes from one material to another, discontinuities in the pipe due to changes in pipe size or material or due to connections of sections, tees, or elbows will introduce errors into the results. For example, a leak on a lateral could be pinpointed as being at the connection between the lateral and the water main. However, this method does give the most analytically precise measure of a leak's location.

The training period required to become proficient at using electronic techniques is longer than for the mechanical methods. The operator needs basic high school level mathematics training and familiarity with an oscilloscope. A period of 1 month's training with an experienced surveyor is estimated.

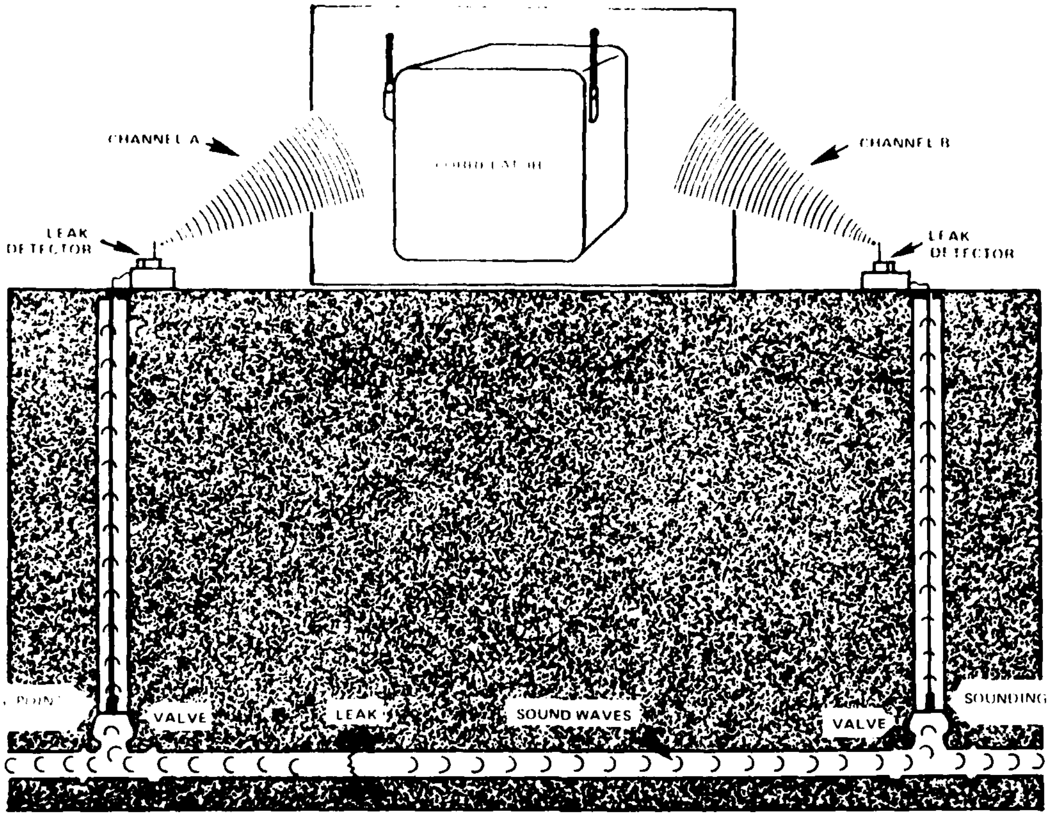

Figure 10. Principle of noise correlation for pinpointing leaks.

Miniprobe Sensors

This technique involves placing a small probe containing a radio transmitter into the distribution system.[9] A surface sensor is used to determine movement of the miniprobe, which can be controlled by opening and closing valves and fire hydrants. If there are no leaks, this opening and closing procedure will dictate the flow in the pipe. However, if a major leak exists in the pipe under study, the probe will move to the location of the leak. This technique is expensive and labor-intensive because it involves exposing the buried pipe and inserting the probe directly into the main. It can be useful, though, particularly in cases involving large leaks in plastic piping, which transmits sound more poorly than does metallic pipe.

Tracer Gases

Tracer gas methods are expensive and complicated due to the requirement for dewatering lines and the complex detection equipment involved.[10] Of the various gases

[9]J. W. Male, R. R. Noss, and I. C. Moore, *Identifying and Reducing Losses in Water Distribution Systems*, Report to the Environmental Engineering Program, University of Massachusetts (December 1983).

[10]L. J. Blythe, *Leak Detection Technology: A Benefit Cost Appraisal of Computerized Monitoring in Water Supply Systems*, Masters Thesis, Massachusetts Institute of Technology (1984).

used, nitrous oxide is heavier than air, water-soluble, and can be detected by infrared methods. Although using this gas precludes line dewatering, the infrared detection equipment needed is expensive and samples must be taken at the pipe level. Helium-air tracer mixtures require line dewatering but are easier to detect using thermal or sonic equipment. Methane-nitrogen and methane-argon also have been used as tracer gases with flame ionization as the detection method. However, the methane techniques can receive interference from leaking gas lines or the presence of natural gas. In the case of argon, comparative sonic methods can be used to confirm the source as the water main, but this gas is heavier than air and must be sampled at the pipeline level.

These methods are extremely expensive compared to sonic surveys[11] and should be conducted only when sonics are impractical. One case in which these techniques may be useful is after a major break has occurred and has been isolated by closing valves. In this case, the line is already in the process of dewatering, if not completely dewatered. Furthermore, sonic techniques are not useful because the water flow has been stopped in response to the emergency situation. Tracer gases could be used in this case to pinpoint the break's location.

Infrared Photography

This method is applicable when the ground temperature is lower than that of the potable water. Large leaks that may not cause water to bubble to the surface may put enough heat into the surrounding soil to raise the local temperature. Since infrared photography can be used to locate heat sources, a photograph showing localized elevated soil temperature may indicate water is pooling at a certain point.

This method is subject to interference from other heat sources. For example, if a steam line occupies the same right of way as a potable line, the heat input from a water leak may be insignificant compared to the heat loss from the steam line.

FESA applied this method at the Aliamanu Military Reservation in attempting to pinpoint leakage in a plastic distribution system.[12] Acoustic methods had failed because plastic does not transmit sound well, and the jointing method used in the system dampened sound even more. The infrared photography also proved ineffective, however, due to the relatively constant ground temperature in Hawaii.

This method requires sophisticated photographic equipment and highly trained personnel to interpret the results. It should be considered only when sonic methods fail, and then should be weighed against the possibility of using tracer gases or an inpipe miniprobe. However, unlike the latter two methods, infrared photography is an option available from FESA.

Other Methods

The water treatment industry sometimes uses methods other than the ones described to detect leaks. These methods often are innovative uses of existing technology. As one paper relates, a situation developed twice in which a main break

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[11] P. M. Heim.

[12] Facilities Engineering Support Agency Report E-82111, *Aliamanu Military Reservation Water Leak Detection Survey, Fort Shafter, Hawaii* (USACE, December 1982).

technology. As one paper relates, a situation developed twice in which a main break occurred and water followed an abandoned electric conduit into a basement.[13] Emergency personnel turned off the water, but when repair crews arrived on site, they had no indication of where the break was located. Moreover, they could not turn the water back on without causing additional damage to the basement. This dilemma was solved by pressurizing the line with air and sounding in the usual way. The first time this was tried it took longer than usual to pinpoint the break because the sound was quite different. The break was found to be submerged in a pool of water and the escaping air was causing a bubbling sound.

Pumping or cycling has also worked in some cases.[14] This method was used to locate a leak on a relatively low-pressure (27-psi), 8-in. main in a city park that had several hundred feet of pipe between valves and no other connections to sound. The leak could be heard only on one valve because the sound was not loud and the entire distance between the valves was under sod. To complicate matters more, the main made several turns between the valves, and pipeline records did not give even approximate locations. With a main under sod, driving sounding rods usually is the logical method but, due to incomplete pipeline records, it was decided to try pumping the leak to make it surface. This was done by turning the water on and off repeatedly over a period of time to allow the saturated soil around the leak to slump to the bottom of the void, perhaps plugging the escape route the leak had been using. In this case, the water was turned off and after an hour or so turned back on, with this cycle repeated over a period of approximately 5 hr. Upon returning to the leak area the last time, a large, soggy place was observed and further investigation revealed a small area where the sod layer was floating on a water-filled void.

Another method has evolved for checking several miles of main that usually has only a limited number of services and few hydrants and valves. Every water system has numerous deadends, most of which are around fringes of the system in areas where mains are being extended. Normally, these areas have little leakage because they are relatively new--but even new construction sometimes leaks. Since the probability of leaks actually existing is low, the surveyor should not spend too much time checking it; yet, to do a thorough survey, it must be investigated. As a simple procedure, the operator can shift to night work and between the hours of 0130 and 0430, check several of these deadends by closing the single valve that controls each main, leaving it closed a few minutes, and then opening it very slowly while listening on the valve key. When water is heard to start through the valve, the operator stops turning and listens; if the flow dies out after a few minutes or if there is no flow at all, it is safe to assume no significant leakage exists and the check for that section of the main is completed. If the flow does not die out, the operator should continue slowly opening the valve while listening. Knowing the number of turns the valve has been opened and the volume of sound heard will give a fair idea of the amount of water involved. By repeating this process along the main, the leak area can be localized in a relatively short time.

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[13] G. N. Zelch, "Sonic Leak Detection," *Proceedings of the 1984 Preconference Seminar on Hydraulics and Water Loss Control* (American Water Works Association, 1984).
[14] G. N. Zelch.

6 ECONOMIC ANALYSIS

A cost-benefit analysis of leak detection and repair allows a program's effectiveness to be determined. Two methods can be used to calculate the benefits: the first determines all existing retail costs involved in treatment and distribution of water (generally called O&M costs); the second method considers the marginal cost of supplying the water lost to leakage as if new facilities were required. The second way includes both O&M costs and construction/expansion of facilities. Installations with demands at or near their maximum treatment capacity will benefit directly from leak control at the marginal cost; those with excess capacity for treatment will save only O&M costs until demand increases.

Costs

Costs of a leak detection study will vary depending on the method chosen to conduct the study. The current state of the art is electronic sonic detection with noise correlation to pinpoint the leaks. Equipment can be purchased or rented or the services can be contracted. Table 2 shows the cost of some leak detection equipment. As is evident from the table, there is a wide price range for the hardware. The cost differences among electronic devices may arise from the inclusion of options and the level of sophistication in signal processing (noise filtering), which ranges from no filters upward. Although the equipment listed is not directly comparable, this table is a useful source list with points of contact for further information.

In a report to the California Department of Water Resources,[15] Boyle Engineering Corporation (BEC) developed cost estimates for conducting a leak survey and repairing the leaks. Table 3 summarizes costs based on three study sites at which leakage surveys were conducted. The benefits were estimated as the value of the water lost over a 2-year period. Costs were those actually incurred, and the benefit-to-cost (B/C) ratio was calculated based on the retail cost of water (Table 3).

Table 3 shows just one method of estimating the costs associated with a leak survey. The survey cost can vary dramatically. The excessively high cost for Poway was attributed in part to the small size of the distribution system surveyed. However, this result did not produce a disadvantageous B/C ratio. The only case of a B/C ratio less than one was in the Serrano Irrigation District study, which also had the lowest amount of leakage. When using the marginal B/C ratio (as if new facilities were required to supply the lost water), all studies had ratios greater than one.

Based on the three study sites, BEC developed generalized cost estimates for supporting a leak detection team and repairing leaks. A value of $225/day was estimated for the cost of leak detection equipment and crew, with $540/leak estimated as the repair cost. The actual cost of repair varies greatly and is related to the type of work needed. The cost of repairing a service connection is at least an order of magnitude less than repairing a main buried in a street.

[15]Boyle Engineering Corp., *Municipal Leak Detection Program, Loss Reduction—Research and Analysis* (State of California Department of Water Resources, August 1982).

Table 2

Costs of Various Leak Control Equipment and Training (1985 Dollars)

Type	Company	Model	Purchase Price ($)
Mechanical-Sonic	Pollard	Aquaphone	10.00
	Pollard	Geophone	245.00
Electronic-Sonic	Fisher Labs	LT-10A	480.00
		XLT-20	1,450.00
	Fluid Conservation Systems	L100	2,400.00
	Goldak	777	510.00
	Heath	Aqua-Scope	1,250.00
		Soni-Kit	2,550.00
	Metrotech	200L	615.00
	Subtronic	WL200	1,225.00
Amplitude attenuation	AELL	AELL2000	7,450.00
Noise correlator	Fluid Conservation Systems	C2000 - Model I	34,500.00
	Subtronics (Japan)	LC1000 (1)	28,500.00
	ARLAT, Inc. (Canada)	MURRAY III	18,000.00
	Reten (Germany)	RC-8151-2 & RC-8165	33,500.00
	Metravib (France)	DF-1001	37,500.00

Training Courses	Company	Description	Cost ($)
Slide/Tape	Heath	-----	250.00
In-Person Demonstration	Pitometer	One week	3,000.00
	Fluid Conservation Systems	Includes Correlator Instruction	3,400.00

Table 3

Cost Estimates From California Water Study (1982 Dollars)*

Location	Distance Surveyed (mi)	No. of Leaks	Survey Cost $	Survey Cost $/mi	B/C**	MB/C***
Petaluma	25.5	31	1791	70	3.33	4.2
Serrano	33.0	10	2689	82	0.51	2.1
Poway	9.8	21	2576	261	1.55	4.9

*Source: Boyle Engineering Corp., *Municipal Leak Detection Program, Loss Reduction—Research and Analysis* (State of California Department of Water Resources, August 1982). Used with permission.
**Benefit-cost ratio for retail value of water.
***Marginal benefit-cost ratio for retail value of water. See "source" above for calculations.

For many years, the Philadelphia Water Department has had an active leak control program that includes leak detection crews and service contracts. The costs for conducting a leak survey are related to the methods used and range from $123/mi using the noise correlator and testing the system only at every valve to $1258/mi using sonic methods but surveying from curbstop to curbstop (i.e., at every house connection). The second method is much more time consuming than the first, but also is more accurate. The cost of each method is approximately the same when compared on the basis of dollars per volume of water saved. Both surveys are estimated to cost $42/million gallons water saved. The retail cost of treating water in Philadelphia is on the order of $100/million gallons, so a B/C ratio of 2.5 is realized even though treatment costs in Philadelphia ($0.10/1000 gal) are very low.

In one report on the savings derived from leakage repair at several communities, it was not possible to determine the B/C ratio because the costs were not given.[16] However, it was observed that the water cost is an important factor. As an example, a community that treats 2 million gal water/day may not benefit from repairing leakage that accounts for 10 percent of its water supply if it costs only $0.06/1000 gal to treat the water. However, if that same community were purchasing bulk water at $1.00/1000 gal, repairing leakage of even 10 percent of total water produced may be beneficial.

[16] J. F. Curtiss, "Water Audit--Conservation, Cost Savings, and More," presented at the American Society of Civil Engineers National Specialty Conference, Water Supply--The Management Challenge (March 1983).

A separate study[17] conducted at Des Plaines, IL, reports that 64 leaks were found, representing an estimated cumulative 1 million gal/day. Repairing these leaks would lead to an annual savings of $228,000 based on the purchase price of water ($0.71/1000 gal) from Des Plaines' supplier. Thus, evidence from the water industry suggests leak detection and repair can result in substantial cost savings.

Estimated Benefits

Based on the above discussion, a method can be developed to estimate benefits attainable from a detailed leak survey. This estimate will be based on a water audit that compares minimum nighttime demand to average daily demand, the retail cost of water treatment (or purchased water cost), and the length of main in each subdistrict to be surveyed.

Army policy is that a ratio of less than 40 percent for minimum nighttime demand to average daily demand will be considered acceptable.[18] Any loss greater than this amount will be considered potentially recoverable. The value of purchasing and treating this amount of water over a 2-year period will be weighed against the estimated cost of conducting the survey.

As an example to explain the method, the hypothetical distribution system in Figure 3 can be used to discuss an analysis by subdistricts. Tables 4 through 9 give results of a hypothetical survey for the seven districts denoted A through G. These tables represent potential costs and benefits for a range of values for five parameters: cost of survey per mile, cost of repair per leak, number of leaks per mile, remaining minimum-to-average ratio, and cost of water per 1000 gal.

Cost of Survey per Mile

This cost has been discussed. The overall estimates range from $60/mi to over $1200/mi. Two estimates were used in calculating the tables--$100/mi and $500/mi.

Cost of Repair per Leak

This cost also has been discussed. The value depends greatly on the type of leak found and its location (e.g., under sod or pavement). Two values were selected--$500/leak, which represents a value less than that estimated by most sources (for major leaks) and would indicate that most leaks discovered were minor, and $750/leak, which represents the top of the range for leak repair costs as reported in the literature.[19]

Number of Leaks per Mile

This parameter is one of the most difficult to estimate because leaks can be a function of soil type, pipe material, frost penetration, and other factors. Two values are available from the literature. BEC estimated that for the State of California, a total of 23,000 leaks would be discoverable in 31,200 mi of water main for a rate of 0.75 leaks/mi

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[17] J. F. Curtiss and P. A. Lohmiller, "Computerized Distribution Records--CADD Paves the Way," *JAWWA*, Vol 76, No. 7 (1984).

[18] ETL 1110-2-294.

[19] G. N. Zelch.

Table 4

Costs and Estimated Benefits for Low Detection/Repair and Low Water Costs (1985 Dollars)*

Sub-district	Avg. Daily Flow (gpm)	Min. Night Flow (gpm)	Ratio Min.: Avg.	Rec. Leak (gpm)**	Value of Lost Water ($)***	Length of Main (mi)	Survey Cost ($)	Repair Cost ($)	Total Cost ($)	B/C Ratio
A	175	75	0.429	13.39	1,407.86	7.0	700	875.00	1,575.00	0.89
B	75	50	0.667	20.83	2,190.00	1.5	150	187.50	337.50	6.49
C	300	230	0.767	118.83	12,491.76	9.6	960	1,200.00	2,160.00	5.78
D	250	95	0.380	12.35	1,298.23	5.8	580	725.00	1,305.00	0.99
E	350	220	0.629	83.29	8,754.99	13.0	1,300	1,625.00	2,925.00	2.99
F	300	85	0.283	2.83	297.84	7.3	730	912.50	1,642.50	0.18
G	400	70	0.175	0.00	0.00	8.1	810	1,012.50	1,822.50	0.00
Total	1850	825	0.446		26,440.68	52.3	5,230	6,537.50	11,767.50	2.25

*Assumes survey of whole system and cost of survey per mile = $100; cost of repair per leak = $500; number of leaks per mile = 0.25; remaining min./avg. ratio = 0.25; and cost of water per 1000 gal = $0.10.
**Recoverable leakage = (ratio [col 4] - remaining ratio) x minimum flow (col 3).
***Calculated for 2 year period.

Table 5

Costs and Estimated Benefits for Low Detection/Repair and Medium Water Costs (1985 dollars)*

Sub-district	Avg. Daily Flow (gpm)	Min. Night Flow (gpm)	Ratio Min.: Avg.	Rec. Leak (gpm)**	Value of Lost Water ($)***	Length of Main (mi)	Survey Cost ($)	Repair Cost ($)	Total Cost ($)	B/C Ratio
A	175	75	0.429	13.39	7,039.29	7.0	700	875.00	1,575.00	4.47
B	75	50	0.667	20.83	10,950.00	1.5	150	187.50	337.50	32.44
C	300	230	0.767	118.83	62,458.80	9.6	960	1,200.00	2,160.00	28.92
D	250	95	0.380	12.35	6,491.16	5.8	580	725.00	1,305.00	4.97
E	350	220	0.629	83.29	43,774.97	13.0	1,300	1,625.00	2,925.00	14.97
F	300	85	0.283	2.83	1,489.20	7.3	730	912.50	1,642.50	0.91
G	400	70	0.175	0.00	0.00	8.1	810	1,012.50	1,822.50	0.00
Total	1850	825	0.446		132,203.42	52.3	5,230	6,537.50	11,767.50	11.23

*Assumes survey of whole system and cost of survey per mile = $100; cost of repair per leak = $500; number of leaks per mile = 0.25; remaining min./avg. ratio = 0.25; and cost of water per 1000 gal = $0.50.
**Recoverable leakage = (ratio [col 4] - remaining ratio) x minimum flow (col 3).
***Calculated for 2-year period.

Table 6

Costs and Estimated Benefits for Low Detection/Repair and High Water Costs (1985 Dollars)*

Sub-district	Avg. Daily Flow (gpm)	Min. Night Flow (gpm)	Ratio Min.: Avg.	Rec. Leak (gpm)**	Value of Lost Water ($)***	Length of Main (mi)	Survey Cost ($)	Repair Cost ($)	Total Cost ($)	B/C Ratio
A	175	75	0.429	13.39	14,078.57	7.0	700	875.00	1,575.00	8.94
B	75	50	0.667	20.83	21,900.00	1.5	150	187.50	337.50	64.89
C	300	230	0.767	118.83	124,917.60	9.6	960	1,200.00	2,160.00	57.83
D	250	95	0.380	12.35	12,982.32	5.8	580	725.00	1,305.00	9.95
E	350	220	0.629	83.29	87,549.94	13.0	1,300	1,625.00	2,925.00	29.93
F	300	85	0.283	2.83	2,978.40	7.3	730	912.50	1,642.50	1.81
G	400	70	0.175	0.00	0.00	8.1	810	1,012.50	1,822.50	0.00
Total	1850	825.0	0.446		264,406.83	52.3	5,230	6,537.50	11,767.50	22.47

*Assumes survey of whole system and cost of survey per mile = $100; cost of repair per leak = $500; number of leaks per mile = 0.25; remaining min./avg. ratio = 0.25; and cost of water per 1000 gal = $1.
**Recoverable leakage = (ratio [col 4] - remaining ratio) x minimum flow (col 3).
***Calculated for 2-year period.

Table 7

Costs and Estimated Benefits for High Detection/Repair and Low Water Costs (1985 Dollars)*

Sub-district	Avg. Daily Flow (gpm)	Min. Night Flow (gpm)	Ratio Min.: Avg.	Rec. Leak (gpm)**	Value of Lost Water ($)***	Length of Main (mi)	Survey Cost ($)	Repair Cost ($)	Total Cost ($)	B/C Ratio
A	175	75	0.429	2.14	225.26	7.0	3,500	3,937.50	7,437.50	0.03
B	75	50	0.667	13.33	1,401.60	1.5	750	843.75	1,593.75	0.88
C	300	230	0.767	84.33	8,865.12	9.6	4,800	5,400.00	10,200.00	0.87
D	250	95	0.380	0.00	0.00	5.8	2,900	3,262.50	6,162.50	0.00
E	350	220	0.629	50.29	5,286.03	13.0	6,500	7,312.50	13,812.50	0.38
F	300	85	0.283	0.00	0.00	7.3	3,650	4,106.25	7,756.25	0.00
G	400	70	0.175	0.00	0.00	8.1	4,050	4,556.25	8,606.25	0.00
Total	1850	825	0.446		15,778.01	52.3	26,150	29,418.75	55,568.75	0.28

*Assumes survey of whole system and cost of survey per mile = $500; cost of repair per leak = $750; number of leaks per mile = 0.75; remaining min./avg. ratio = 0.40; and cost of water per 1000 gal = $0.10.
**Recoverable leakage = (ratio [col 4] - remaining ratio) x minimum flow (col 3).
***Calculated for 2-year period.

Table 8

Costs and Estimated Benefits for High Detection/Repair Costs and Medium Water Costs (1985 Dollars)*

Sub-district	Avg. Daily Flow (gpm)	Min. Night Flow (gpm)	Ratio Min.: Avg.	Rec. Leak (gpm)**	Value of Lost Water ($)***	Length of Main (mi)	Survey Cost ($)	Repair Cost ($)	Total Cost ($)	B/C Ratio
A	175	75	0.429	2.14	1,126.29	7.0	3,500	3,937.50	7,437.50	0.15
B	75	50	0.667	13.33	7,008.00	1.5	750	843.75	1,593.75	4.40
C	300	230	0.767	84.33	44,325.60	9.6	4,800	5,400.00	10,200.00	4.35
D	250	95	0.380	0.00	0.00	5.8	2,900	3,262.50	6,162.50	0.00
E	350	220	0.629	50.29	26,430.17	13.0	6,500	7,312.50	13,812.50	1.91
F	300	85	0.283	0.00	0.00	7.3	3,650	4,106.25	7,756.25	0.00
G	400	70	0.175	0.00	0.00	8.1	4,050	4,556.25	8,606.25	0.00
Total	1850.0	825	0.446		78,890.06	52.3	26,150	29,418.75	55,568.75	1.42

*Assumes survey of whole system and cost of survey per mile = $500; cost of repair per leak = $750; number of leaks per mile = 0.75; remaining min./avg. ratio - 0.40; and cost of water per 1000 gal = $0.50.
**Recoverable leakage = (ratio [col 4] - remaining ratio) x minimum flow (col 3).
***Calculated for 2-year period.

Table 9

Costs and Estimated Benefits for High Detection/Repair and High Water Costs (1985 Dollars)*

Sub district	Avg. Daily Flow (gpm)	Min. Night Flow (gpm)	Ratio Min.: Avg.	Rec. Leak (gpm)**	Value of Lost Water ($)***	Length of Main (mi)	Survey Cost ($)	Repair Cost ($)	Total Cost ($)	B/C Ratio
A	175	75	0.429	2.14	2,252.57	7.0	3,500	3,937.50	7,437.50	0.30
B	75	50	0.667	13.33	14,016.00	1.5	750	843.75	1,593.75	8.79
C	300	230	0.767	84.33	88,651.20	9.6	4,800	5,400.00	10,200.00	8.69
D	250	95	0.380	0.00	0.00	5.8	2,900	3,262.50	6,162.50	0.00
E	350	220	0.629	50.29	52,860.34	13.0	6,500	7,312.50	13,812.50	3.83
F	300	85	0.283	0.00	0.00	7.3	3,650	4,106.25	7,756.25	0.00
G	400	70	0.175	0.00	0.00	8.1	4,050	4,556.25	8,606.25	0.00
Total	1850	825	0.446		157,780.11	52.3	26,150	29,418.75	55,568.75	2.84

*Assumes survey of whole system and cost of survey per mile = $500; cost of repair per leak = $750; number of leaks per mile = 0.75; remaining min./avg. ratio = 0.40; and cost of water per 1000 gal = $1.
**Recoverable leakage = (ratio [col 4] - remaining ratio) x minimum flow (col 3).
***Calculated for 2 year period.

of main. At the other end of the spectrum, USACE estimates there could be 30 leaks in a hypothetical system of 121.2 mi of pipe for an overall rate of 0.25 leaks/mi of main.[20] These two values, 0.25 and 0.75, were used in the analysis.

Remaining Minimum/Average Ratio

This ratio is used to estimate the amount of water that could be saved if a leak detection and maintenance program were completed. Although the Army states a value of less than 0.4 would indicate water loss is not a major problem, data from Daytona Beach, FL indicate a ratio of less than 0.4 was excessive. For this analysis, a value of 0.25 was used as an estimate of the best results that could be achieved by a leak detection study. This value is not excessively low according to results[21] on residential water use in 23 areas across the United States. This study determined minimum night flows as well as peak day, average day, and other parameters. The average minimum flow ratio was 0.089 with a standard deviation of 0.042; the highest value reported was 0.25. Thus, attaining this level is feasible and, in fact, ratios of lower than 0.25 may be attainable, resulting in even higher B/C ratios.

Cost of Water per 1000 gal

This parameter represents the value of resource conserved. The values in the literature (discussed previously) range from $0.10/1000 gal to >$1.00/1000 gal. In this analysis, $0.10, $0.50 and $1.00/1000 gal were used.

Approach for Making Estimates

All assumptions were grouped into a set of "most advantageous" and "least advantageous" for success of a leak detection/leak repair program. The most advantageous conditions would be a low cost of survey per mile ($100), low cost for repairs ($500/leak), low number of leaks per mile (0.25), and allow remaining ratio (0.25) of minimum flow to average daily flow (i.e., a high success rate at repairing leaks). The least advantageous conditions would be a high cost of survey per mile ($500), high cost of leak repairs ($750/leak), high number of leaks per mile (0.75), and a high remaining ratio (0.75) of minimum flow to average flow. These least advantageous and most advantageous sets of circumstances were analyzed together at the three different water costs.

For the example, data from a water audit were fabricated around the system in Figure 3 for average flow, minimum night flow, and miles of main in the system. These values are shown in columns 2, 3, and 7 in Tables 4 through 9 and are identical in each example. (The point of the example is to demonstrate how each parameter contributes to the total potential benefit of a leak detection program.) The overall average ratio of minimum night flow to average flow is 0.44; thus, this system has no obvious problems with water leakage, but the examples demonstrate that cost savings can still be attained depending on the cost of water and repairs.

This example does not include savings that could be achieved by decreasing the size of future expansion. Any savings in water demand could reduce the size of construction/expansion of facilities, which would be reflected in lowered capital costs. These capital costs should be amortized over the life of the project, and may or may not be

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[20] ETL 1110-2-294.

[21] F. P. Linaweaver, Jr., J. C. Geyer, and J. B. Wolff, *A Study of Residential Water Use* (Federal Housing Administration, 1955).

significant in the overall cost analysis for a leak detection/repair program. This value should be computed for Army facilities that operate their own water systems and expect to require expansion in the near future (0 to 5 yr).[22] However, the examples in this report show that the leak detection survey often can be justified solely on the basis of the savings in O&M accrued over a 2-year period.

The approach for estimating benefits in the example is similar to the method explained in ETL 1110-2-294 except in two ways: it allows an estimate of areas that may benefit from a leak survey (by the water audit) and incorporates an estimate of water that can be saved. Furthermore, results of the preliminary study (the water audit) could indicate that the followup study (the leak detection survey) would be unnecessary.

Tables 4 through 9 show a range of conditions, some favorable and others not, to conducting a leak survey. For the low-cost detection and repair scenario (Tables 4 through 6), the program always shows a B/C ratio greater than one based solely on reduced O&M costs. For the high-cost detection and repair program (Tables 7 through 9), the example using the low-cost water (Table 7) indicates the cost of the survey would not equal the benefits obtained. However, even with the high costs, the survey would be beneficial for facilities paying more than $0.50/1000 gal water.

The data in Tables 4 through 9 were developed as if a contract were let to survey the entire system, regardless of the audit results. Thus, survey and repair costs are entered in each row. If the contract were written to exclude areas that indicated no substantial water leakage (as determined by the water audit), the B/C ratio would improve. This is the case shown in Tables 10 though 12. Only the high cost for survey and repair is shown here, assuming that a contractor would bid higher for the survey if the substantial leakage condition were included. The total or overall B/C ratio improves under this procedure; however, there still is no benefit for the lowest cost water.

The data in Tables 4 through 12 were calculated on a Lotus-123 spreadsheet. Any installation wishing to evaluate its overall potential for cost savings may receive the program used for these calculations from USA-CERL, ATTN: EN Water Quality Management Team, P.O. Box 4005, Champaign, IL 61820, 800-USA-CERL outside Illinois, 800-252-7122 inside the state. Data required for the analysis are the values for the five parameters shown in the footnotes of the tables, and data in columns 2 (average daily flow), 3 (minimum nighttime flow, which can be determined from master meters at a water treatment plant or at connection to a public supplier), and 7 (length of main, which is reported for several Army installations in Table 1 but should be verified). The program could also be transferred via floppy diskette to anyone with access to and familiarity with the Lotus-123 program on an IBM-PC.

Intangible Benefits

Potential benefits derived from a leakage detection/repair program include:

- Correction of a problem that could lead to total breakage of a water main.
- Avoidance of water damage that could result from flooding of basements and low-lying areas.

[22]ETL 1110-2-294.

Table 10

Loss Area Survey—Costs and Estimated Benefits for High Detection/Repair and Low Water Costs (1985 Dollars)

Sub-district	Avg. Daily Flow (gpm)	Min. Night Flow (gpm)	Ratio Min.: Avg.	Rec. Leak (gpm)*	Value of Lost Water ($)**	Length of Main (mi)	Survey Cost ($)	Repair Cost ($)	Total Cost ($)	B/C Ratio
A	175	75	0.429	2.14	225.26	7.0	3,500	3,937.50	7,437.50	0.03
B	75	50	0.667	13.33	1,401.60	1.5	750	843.75	1,593.75	0.88
C	300	230	0.767	84.33	8,865.12	9.6	4,800	5,400.00	10,200.00	0.87
D	250	95	0.380	0.00	0.00	5.8	0	0.00	0.00	0.00
E	350	220	0.629	50.29	5,286.03	13.0	6,500	7,312.50	13,812.50	0.38
F	300	85	0.283	0.00	0.00	7.3	0	0.00	0.00	0.00
G	400	70	0.175	0.00	0.00	8.1	0	0.00	0.00	0.00
Total	1850	825	0.446		15,778.01	52.3	15,550	17,493.75	33,043.75	0.48

*Recoverable leakage = (ratio [col 4] - remaining ratio) x minimum flow (col 3).
**Calculated for 2-year period.

Assumptions: survey of whole system but leak pinpointing only in areas exceeding acceptable min./avg. ratio and cost of survey per mile = $500; cost of repair per leak = $750; number of leaks per mile = 0.75; remaining min./avg. ratio = 0.40; and cost of water per 1000 gal = $0.10.

Table 11

Loss Area Survey--Costs and Estimated Benefits for High Detection/Repair and Medium Water Costs (1985 Dollars)

Sub-district	Avg. Daily Flow (gpm)	Min. Night Flow (gpm)	Ratio Min.: Avg.	Rec. Leak (gpm)*	Value of Lost Water ($)**	Length of Main (mi)	Survey Cost ($)	Repair Cost ($)	Total Cost ($)	B/C Ratio
A	175	75	0.429	2.14	1,126.29	7.0	3,500	3,937.50	7,437.50	0.15
B	75	50	0.667	13.33	7,008.00	1.5	750	843.75	1,593.75	4.40
C	300	230	0.767	84.33	44,325.60	9.6	4,800	5,400.00	10,200.00	4.35
D	250	95	0.380	0.00	0.00	5.8	0	0.00	0.00	0.00
E	350	220	0.629	50.29	26,430.17	13.0	6,500	7,312.50	13,812.50	1.91
F	300	85	0.283	0.00	0.00	7.3	0	0.00	0.00	0.00
G	400	70	0.175	0.00	0.00	8.1	0	0.00	0.00	0.00
Total	1850	825	0.446		78,890.06	52.3	15,550	17,493.75	33,043.75	2.39

*Recoverable leakage = (ratio [col 4] - remaining ratio) x minimum flow (col 3).
**Calculated for 2 year period.

Assumptions: survey of whole system but leak pinpointing only in areas exceeding acceptable min./avg. ratio and cost of survey per mile = $500; cost of repair per leak = $750; number of leaks per mile = 0.75; remaining min./avg. ratio = 0.40; and cost of water per 1000 gal = $0.10.

Table 12

Loss Area Survey—Costs and Estimated Benefits for High Detection/Repair and High Water Costs (1985 Dollars)*

Subdistrict	Avg. Daily Flow (gpm)	Min. Night Flow (gpm)	Ratio Min.: Avg.	Rec. Leak (gpm)**	Value of Lost Water ($)***	Length of Main (mi)	Survey Cost ($)	Repair Cost ($)	Total Cost ($)	B/C Ratio
A	175	75	0.429	2.14	2,252.57	7.0	3,500	3,937.50	7,437.50	0.30
B	75	50	0.667	13.33	14,016.00	1.5	750	843.75	1,593.75	8.79
C	300	230	0.767	84.33	88,651.20	9.6	4,800	5,400.00	10,200.00	8.69
D	250	95	0.380	0.00	0.00	5.8	0	0.00	0.00	0.00
E	350	220	0.629	50.29	52,860.34	13.0	6,500	7,312.50	13,812.50	3.83
F	300	85	0.283	0.00	0.00	7.3	0	0.00	0.00	0.00
G	400	70	0.175	0.00	0.00	8.1	0	0.00	0.00	0.00
Total	1850	825	0.446		157,780.11	52.3	15,550	17,493.75	33,043.75	4.77

*Assumes survey of whole system and cost of survey per mile = $500; cost of repair per leak = $750; number of leaks per mile = 0.75; remaining min./avg. ratio = 0.40; and cost of water per 1000 gal = $1.
**Recoverable leakage = (ratio [col 4] - remaining ratio) x minimum flow (col 3).
***Calculated for 2-year period.

- Potential for reduction in infiltration/inflow into a sanitary sewer.

- Public relations representing the Army as conserver as well as protector of U. S. resources.

Leaks can be considered as breaks waiting to develop. As a leak washes away the surrounding support material, the water main must support its own weight plus any loads (e.g., frost penetration, surface loads due to vehicles) to which it is subjected. Dramatic washout of bedding materials also can lead to roadbed collapse under a heavy load. Either situation leads to a problem much greater than mere water loss. A continuous program of leak detection/repair reduces the chance of a leak contributing to a more serious problem.

Large leaks can discharge enough volume to cause water damage in basements and low-lying areas. Chapter 5 mentions cases in which water from breaks followed abandoned electrical conduits into adjacent basements.[23] In arid regions with clay soils, even small amounts of water can cause the clay to expand, placing new stresses on the main and any surrounding foundations. Damage such as stress fractures in foundation walls and abnormal "settling" in structures may occur without ever being attributed to water leakage.

Infiltration/inflow is a major problem in many wastewater treatment plants nationwide. Water can leak directly into a sanitary sewer, causing no noticeable problems to the water distribution system but increasing the hydraulic load on the sewage treatment plant.

Finally, the public image of the Army as a concerned citizen and a good neighbor can be aided by a water loss prevention program. This effect would be pronounced in water-short regions of the country.

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[23] G. N. Zelch.

Current Needs

A telephone survey of U. S. Army Forces Command and Training and Doctrine Command installations was conducted to determine if leak detection surveys had been completed and if water leakage was considered a major problem. Table 13 gives the results.

As expected, the installations surveyed used few or no methods to search for leaks systematically. There was little concern for the amount of leakage, with most installations replying that leakage was a minor or insignificant problem. However, as discussed in this chapter, the lack of an obvious water loss problem does not imply that cost savings would be impossible if a leakage survey were done.

Table 13 shows that the average cost of water is $0.63/1000 gal. Based on the range of values presented in Tables 4 through 12, it appears there is good potential for cost savings because the B/C ratio was favorable for most cases when the cost of water was greater than $0.50/1000 gal. The data in Table 13 may estimate the actual water treatment cost on the high side, with some extras included that would not be reduced if water use were reduced. However, for installations using public suppliers, the benefit should directly reflect the cost of water shown because reduction in use means lower water bills. The actual B/C ratio also will strongly depend on the amount of water being lost, i.e. the minimum night use-to-average day use ratio.

The FESA Program

The Army's leak detection team operates under the authority of FESA. For information on its methods and availability, contact the Mechanical Branch, Engineering Division, FESA, Fort Belvoir, MD (FTS 544-6462, Autovon 354-6462). This team mainly responds to emergency situations in which water loss (or other fluid loss) is suspected based on events such as extreme water usage and water on the surface. The FESA team is preparing a Standard Operating Procedure (SOP) for its method to allow Army installations to conduct their own leak surveys. Although similar to the intent of this report, the SOP describes only the current FESA method and is intended as an emergency response.

Table 13

Current Leak Detection Methods at Army Installations—Telephone Survey

Installation	Water Source*	Usage (MGD)**	Water Cost/ 1000 gal ($)	Leak Survey Done	Leak Problem	Favor Leak Program
Fort Bragg	S	6	0.59	No	Minor	Yes
Fort Hood	G&P	7	0.20	Yes	Minor	Yes
Fort Bliss	G	1.5-13	0.25	No	Minor	No
Fort Lewis	G	5.5-6(W),15(Su)	0.30	Yes	Major	Yes
Fort Riley	G	4.2	0.35	No	Minor	Yes
Fort Knox	G&S	3.5&7	0.55	No	Minor	Yes
Fort Ord	G	10	0.77***	No	Normal	Yes
Fort Campbell	G	3.5	0.09	Yes	Minor	Yes
Fort Benning	S	8	1.10	Yes	Minor	Yes
Fort Leonard Wood	S	3.5-5	0.45	No	Minor	No
Fort George G. Meade	S	3	0.67	No	Insig	Yes
Fort Belvoir	P	1.7	0.68	No	Minor	Yes
Fort Jackson	S	4	0.27‡	No	Minor	Yes
Fort Devens	G	1.5(W),3.5(Su)	0.46	No	Insig	Yes
Fort Stewart	G	5	0.17	Yes	Insig	Yes
Fort Carson	P	2.5	1.13	No	Normal	Yes
Fort Dix	S&G	2.5	0.74	Yes	Insig	Yes
Fort Lee	P	1.5-2	0.92	No	Sig	Yes
Fort Gordon	S	3	0.60	No	Insig	No
Fort Eustis	P	1.7	0.91	No	Minor	Yes
Fort McClellan	P	1.2-2	0.53‡‡	No	Insig	Yes
Fort Richardson	N/A	4.1	0.37‡‡‡	N/A	N/A	N/A
Fort Pickett	S	1	0.52	No	Minor	Yes
Fort McCoy	G	.25-1	0.90	No	Sig	Yes
Fort Rucker	G	3.2-3.5	0.66	No	Minor	Yes
Fort Gillem	P	0.23	1.25	Yes	Sig	Yes
Fort Polk	G	3.5	1.28	No	Minor	No
Fort Indiantown Gap	P	0.6(W),1.7(Su)	0.68	Yes	Minor	No
Fort Leavenworth	G	3.5-4	0.60	No	Normal	Yes
Fort Monroe	S	1.5	0.63	No	Normal	Yes
Fort Benjamin Harrison	G	0.8	1.35	No	Normal	Yes
Fort Hamilton	P	0.006	0.94	N/A	N/A	N/A
Carlisle Barracks	S	1	0.37	Yes	Normal	Yes
Fort Chaffee	S	0.31	0.48	No	Insig	No
Fort Wainwright	N/A	1.9	0.51‡‡‡	N/A	N/A	N/A
Fort Sill	S	3.8	0.26	No	Minor	No
Fort A.P. Hill	G	0.4	8.33	No	Minor	Yes

Average = 0.63 (excluding last installation)

*S--surface; G--ground; P--public; N/A--not available during phone survey.
**Su--summer demand; W--winter demand.
***Reported as $250/acre-ft.
‡Reported as $400,000/yr.
‡‡Reported as $/cu ft, assumed to be $/ccf (ccf = 100 cu ft).
‡‡‡From 1983 *Facilities Engineering Annual Summary of Operations*, OCE.

7 CONCLUSIONS

Money can be saved from leak detection surveys when applied as a part of regular facility maintenance. Furthermore, implementing these procedures will avoid future emergencies by detecting leaks while they are still small. Small leaks generally do not damage property, but they can develop into major problems if left unchecked and waste money in water treatment and purchases.

The methods reported here should be viewed as a regular O&M procedure that can save money in terms of existing operating costs (or water bills from outside water suppliers) as well as reducing or postponing capital costs for expansion. The B/C ratio, using only real savings from treatment cost and ignoring savings from capital costs, has been shown to be greater than three in some cases, which implies that for every dollar invested, three dollars would be returned in reduced treatment cost or water purchases.

A broad range of leak detection methods is available to the water industry and could be implemented on Army installations. A methodology for conducting a preventive maintenance leak detection survey has been proposed in three levels: (1) "general housekeeping," (2) water audit to determine if excess water loss is occurring, and (3) leak pinpointing.

The first level includes actions normally taken in the private sector when unusually high water bills are received. Since water bills are not issued for each individual user on Army installations, it would be assumed there is some excess loss and each building would be checked for leaks. This is a very conservative assumption, but is the only alternative when water meters are not installed at each connection.

A water audit is a method to identify, but not pinpoint, leakage areas. The water audit is required to judge the amount of leakage. The Army needs to establish to what level the leakage and minimum night flow-to-average day flow ratio can be reduced, i.e., whether 0.25 or 0.4 should be the acceptable ratio. This measure would aid in the further economic evaluation of potential costs and benefits. Establishing this ratio could be the topic of future research.

The third level of the survey involves pinpointing leaks and repairing them in areas with heavy water loss as determined by the water audit. After leaks are repaired, the locations previously tested in the water audit would be retested to determine the effectiveness of the leak detection program.

A method as been presented to estimate the benefit-to-cost (B/C) ratio based on water saved over a 2-year period. A range of values has been presented so that individual installations can judge their chances for successful results based on local conditions such as water cost, pipeline length, and repair cost. Based on the average cost of water paid by Army installations responding to the telephone survey ($0.64/1000 gal), prospects appear very good for highly favorable B/C ratios.

The methods reported here should be viewed as a regular O&M procedure that can save money in terms of existing operating costs (or water bills from outside water suppliers) as well as reducing or postponing captial costs for expansion. The B/C ratio, using only real savings from treatment cost and ignoring savings from capital costs, has been shown to be greater than three in some cases, which implies that for every dollar invested, three dollars would be returned in reduced treatment cost or water purchases.

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